SHOCKED CLOUDS IN THE CYGNUS LOOP

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Final Report

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This grant covers the analysis of ROSAT PSPC and HRI images of the Cygnus Loop, an elderly supernova remnant. The project, as proposed, includes not only the usual analysis of ROSAT data; we are combining the ROSAT data with optical and UV data, and we are performing new model calculations. Many of the pieces of this effort have been accomplished, but we are still in the process of assembling them into the final paper. Here is the status:

Optical Imagery – Hα and [O III] data have been reduced and flux calibrated. Fluxes of specific regions have been extracted for comparison with other work. Flux calibration appears better than 10%.

Echelle Data – Hα and [O III] long slit echelle data have been reduced, and velocities measured from some exposures.

IUE Data – A half-dozen short wavelength spectra have been reduced, and emission line fluxes have been measured.

ROSAT Data – HRI data have been superposed on [O III] images. PSPC data have been fit to determine T, N_H, and in some cases $n_e t$ and abundances in 1' square pixels. We are about to refit these data fixing the abundances of Fe and Si to the depleted values implied by our theoretical models (below). This is not possible within PROS, but we are using a code supplied by Jack Hughes.

Grain Model – Refractory elements (C, Si, Fe) are heavily depleted in the ISM, and they are only slowly liberated from grains by sputtering in million degree gas. We have recently completed a theoretical calculation (Vancura ***et al.*** 1994) from which we can set the elemental abundances as a function of distance from the shock. Note that at Cygnus Loop X-ray temperatures, most of the 1/4 keV X-rays come from Fe and Si. If one fits a spectrum of depleted gas with a theoretical spectrum assuming cosmic abundances, one overestimates the temperature by up to 40%.

The major question we are addressing is whether the blastwave-cloud interaction in the feature known as XA is basically a converging shock in a fairly large cloud ("cloud crushing" as proposed by Hester and Cox) or turbulent stripping of material from the edges of a smaller cloud, as explored in detailed numerical models by Stone and Norman and by Klein, McKee and Colella. Our conclusion is that, although the beginnings of turbulence can be seen in some filaments of XA, the "cloud crushing" picture is far better able to explain the morphology, the velocity structure, and the spectral characteristics of XA.

The full paper on these results is still in preparation, but parts of it are discussed in "An X-ray and Optical Study of a Cloud-Blast Wave Interaction," Levenson ***et al.***, "Precursor Parameters of Non-Radiative Shocks," Raymond, "Shock Wave Structure in the Cygnus Loop," Raymond and Curiel, and "A Study of X-ray and Infrared Emissions from Dusty Nonradiative Shock Waves," Vancura ***et al.***

Publications

"An X-ray and Optical Study of a Cloud-Blast Wave Interaction," N. Levenson, J.R. Graham, J.J. Hester, J.C. Raymond and R. Petre, 1993, presented at Workshop on ***Supernova Remnants and the Physics of Strong Shock Waves***, Raleigh, NC, September 16-18, 1993.

"Precursor Parameters of Non-Radiative Shocks," J.C. Raymond, "***ibid.***

(These two papers are summarized in "Supernova Remnants and the Physics of Strong Shock Waves" by D.C. Ellison ***et al.***, to appear in ***PASP.***)

"Shock Wave Structure in the Cygnus Loop," J.C. Raymond and S. Curiel, 1993, Proc. of conf. on ***Kinematics and Dynamics of Diffuse Astronomical Media***, Manchester, England, March 22-26, 1993, Kluwer, in press.

"A Study of X-ray and Infrared Emissions from Dusty Nonradiative Shock Waves," O. Vancura, J.C. Raymond, E. Dwek, W.P. Blair, K.S. Long and S. Foster, 1994, ***Ap.J.***, in press.